

Low Dc Voltage Measurements

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KEITHLEY

Low dc voltage measurements

Each area of measurement and calibration takes special expertise, low level dc voltages are no exception

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■ Many electrical standard calibrations require the measurement or comparison of low levels of dc voltage. Historically, these measurements were made using precision potentiometers, bridges and ratio sets with sensitive ballistic galvanometer systems being used for null detection. Those having used such systems know the frustration of attempting to make a measurement. It can be said that such technology produced data based as much on "feel" as on readout.

Ballistic galvanometers are highly susceptible to both vibration and overload. Everyone who has used these systems has experienced overload conditions that damaged the galvanometer, the standard being tested or both.

Null detection instrumentation has improved dramatically during the past 30 years. The photocell amplifier has given resolution, and electronic galvanometers have eliminated seismic sensitivity and overload damage. The overall methodology

for low-level measurements remained essentially the same, however, until about six years ago. Keithley Instruments then introduced the model 181 digital nanovoltmeter. (The prefix nano indicates a multiple of 10^{-9} .) This instrument provided potential capability for both higher accuracy measurements and computer interfaced operations. Experience has proven the device to be capable of performing 3 sigma confidence level measurement of 1 nV when under computer control.

Accurate low-level dc measurements requires a fundamental knowledge of thermal effects (Figure 2). In an electrical circuit

each mechanical contact forms a thermocouple junction. The dc voltage levels produced by these junctions are determined by the contact materials and the operating temperature. In a constant-temperature environment, the combination of these junctions

produces a fixed offset voltage that adds to the actual voltage being measured. Ideally, the amount of this offset can be determined by making a normal and reverse polarity measurement of the source. The true voltage (E_t) of the source being tested and thermal offset (E_o) can then be calculated by:

$$E_t = (E_n - E_r)/2 \text{ and } E_o = (E_n + E_r)/2$$

Where: E_n = Normal polarity measurement

E_r = Reverse polarity measurement

In practice, conditions are not ideal due to thermal transients such as movement across the circuit junctions along with minute temperature gradients caused by the making and breaking of switch contacts. These cause the thermal offset voltages to vary. The error factors can be reduced by enclosing the circuits in a thermally-stable environment (like an oil bath), shielding contacts from air currents and allowing time for transients to settle to a constant value. Most important is that the voltage to be measured has reached stability before attempts are made to take data.

Computer control

While computers are capable of generating data with near infinite resolution, the validity is only as good as the technology that produced it. The advantage is that measurements are less susceptible to operator errors when under computer control.



Figure 1. The operator measures voltage differences between cells. A Keithley 181 nanovoltmeter, an apple computer and three Guildline standard cell enclosures are being used.

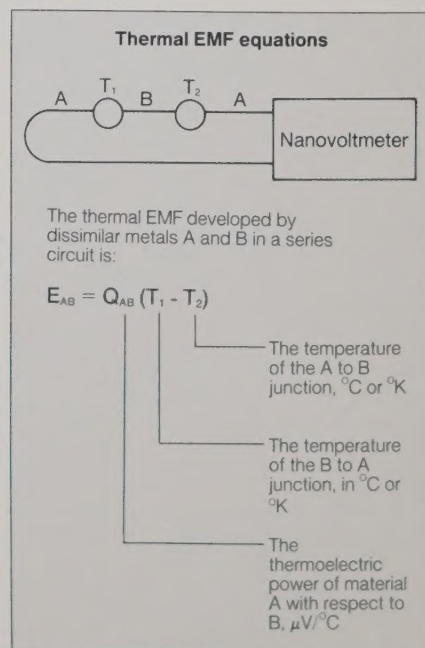


Figure 2. Thermal EMF equations.

The Keithley 181 has features under computer control that can be used to simulate experienced operator judgment. It is necessary in low-level measurements to determine if the system has "settled out."

In manual setups using a precision potentiometer or bridge, this would be the same as pressing the coarse, medium and fine "null sensitivity" controls to obtain a final measurement value. The computer-controlled coarse, medium and fine relates to using the filter out, filter in and damped digital nanovoltmeter functions. The three steps are as follows:

1. **FILTER OUT**—fastest sampling time used to establish an initial confidence level.

- A ten (10) measurement series (A) is taken.
- A ten (10) measurement series (B) is taken.
- If the mean/average of series (A) does not agree with series (B) to within (plus-minus) 10 μV then the process is repeated until it does.

2. **FILTER IN**

- A ten (10) measurement series (A) is taken.
- A ten (10) measurement series (B) is taken.
- If the mean/average of series (A) does not agree with series (B) to within (plus-minus) 100 nV then the process is repeated until it does.

3. **DAMPING IN**—same as FILTER IN with ability to reduce effect of large transients.

- A one hundred (100) measurement series (A) is taken.
- A one hundred (100) measurement series (B) is taken.
- If the mean/average of series (A) does not agree with series (B) to within (plus-minus) 10 nV then the process is repeated until it does.

- The measurement value is the mean of the last (B) series.

Some difference of opinion may exist in the order of filter applications. The logic used here is that the source stability is proven in the FILTER IN position. DAMPING IN for the final measurement series provides added confidence by suppressing higher-level system transients that are not real parts of the measured or compared signals. Regardless of order, the mathematical results normally validate the process.

The filter order, number of samples and voltage cutoffs can vary with the application. The experience under computer control has shown 3 sigma precision certainties as low as 1 nV . This could take hours or be impossible to do manually. With automatic instrumentation it can be done quickly.

The digital nanovoltmeter under computer control is capable of replacing any ballistic, photocell amplifier or electronic galvanometer for metrology laboratory operations. A trend is to use solid-state (Zener Diode) voltage references, although, standard cells are still the mainstay. While accepted as reliable standards, they are delicate and susceptible to damage. Most damage results from operator mistakes. The combination of the model 181 and commercially available standard cell scanners, the Data Proof models 320A or 160A provide a system capable of totally automatic maintenance of voltage references, with inherent protection for these critical standards. A complete package, including software for use on both the HP 9000 and 200 series computers, is also available from Data Proof.

Current comparators

The Guildline model 9930 current comparator remains the ultimate in capability for low voltage dc measurements, however, its internal photocell galvanometer is highly susceptible to overload and does not provide direct readout of measured deviations. This system is accurate but time consuming to operate and lacks computer compatibility. A modification is available for computer interfaceable readout of dial settings. But, since

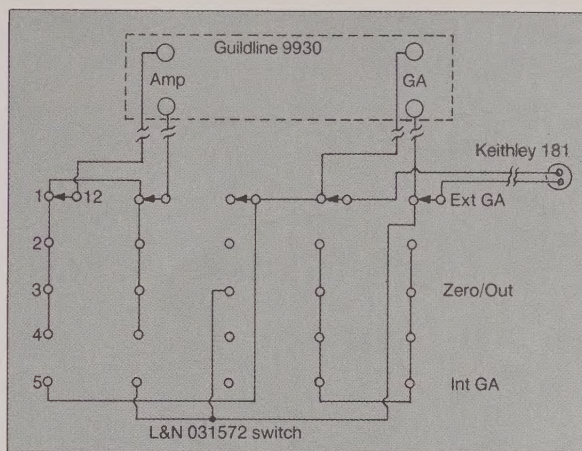


Figure 3. Guildline 9930 external detector circuit.

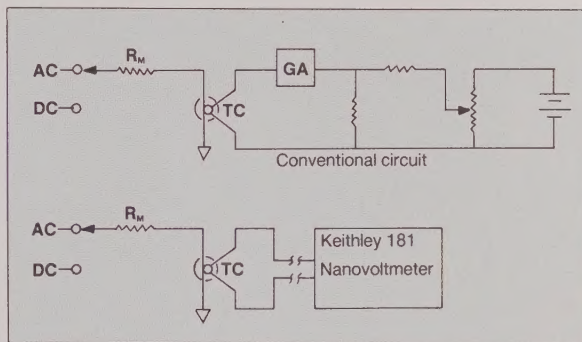


Figure 4. ac/dc transfer setups.

internal null detector has no such capability, even semi-automation is not possible in factory provided configurations. Fortunately, connections to the photocell amplifier are made on accessible binding posts. This makes an external detector an alternative. The circuit shown (Figure 3) can use a digital nanovoltmeter in addition to the internal detector. This circuit also allows, in the short (ZERO/OUT) position use of the Guildline 9930 as a high-accuracy, low-voltage dc source. When comparator leads are shorted, this can also be used to calibrate the lower ranges of the digital nanovoltmeter.

Transfer standards

The traditional way to compare acv to dcv is the thermal transfer voltmeter (Figure 4). These devices are nothing more than a heater coupled to a thermal junction with a resistive voltage multiplier. The thermal junction produces a low voltage dc output in the region of 7 millivolts or less at full rating whether ac or dc is applied to the heater.

The transfer process is done by applying an ac voltage and nulling the output with a galvanometer against the low voltage produced by the Lindeck-type potentiometer. The ac voltage is then replaced by a dc voltage that is adjusted for null. When the dc voltage can be measured accurately, the ac level is known. A major limitation of this process is the drift in the output of both the thermal converter and the Lindeck source. Thermal transfer measurements are time-consuming and frustrating. The 181 generally can be used to replace both the traditional null detector and Lindeck potentiometer circuitry.

In operation, the ac voltage is applied and the thermal converter output measured. After a stabilized reading is noted, the zero function is activated. The ac is then replaced by dc, and the dc source is adjusted again for the reference zero level. This works on simple thermal converters and may also be used with

commercial instruments such as the Fluke 540B to improve capability.

The nanovoltmeter is also ideal for calibration of both low ohmic value standard resistors and shunts. Depending on source stability, the diagram shown (Figure 5) can provide a fully automated measurement system. The automated current source that is capable of current reversal can be used to eliminate zero and thermal offset errors.

A digital nanovoltmeter also can be used as a null detector with classical design laboratory resistance bridges and ratio sets. With a calibrated voltage or current source (Figure 6), a direct reading deviation, computer interfaced configuration, is possible.

A digital nanovoltmeter can be used to give better methods and computer interface for metrology operations traditionally done manually. The digital nanovoltmeter can extend the capability of "classic" instruments that may be currently considered obsolete.

While this article has theme instruments, such exist only because of the uniqueness of the devices and their applications. The intent is to show how metrology operations can be improved with commercially available instrumentation. ■

1. "A 32 Channel Scanner System With 50 Nanovolt Thermals for Standard Cell Measurements," James Marshall, Hewlett Packard Co.

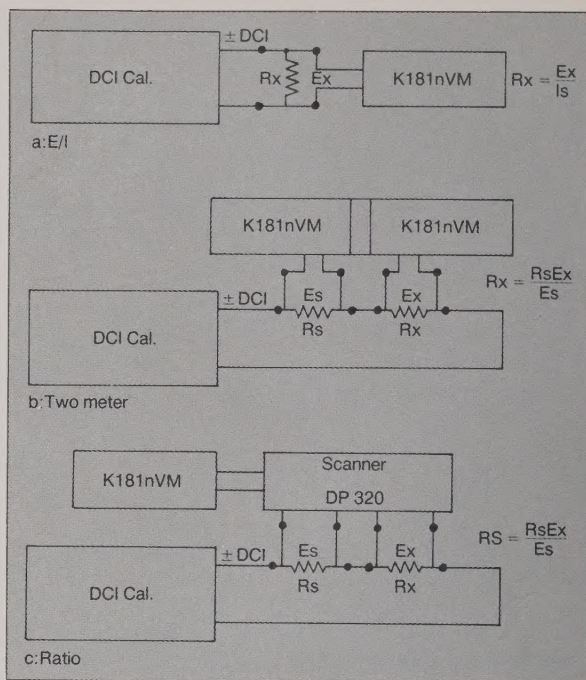


Figure 5. Shunt calibration.

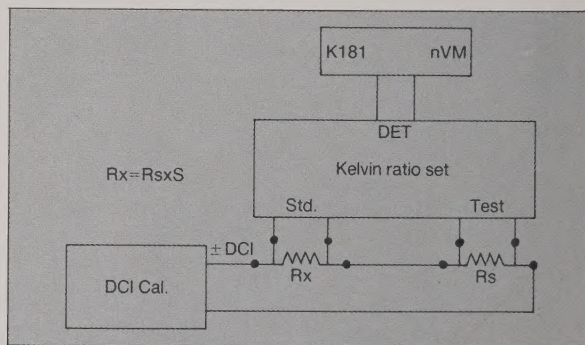


Figure 6. Bridge/ratio set nV meter.

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